Unlimited

VOYAGER PLANETARY QUARANTINE OPTICAL CHARACTERISTICS OF VIABLE MICROORGANISMS

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VOYAGER PLANETARY QUARANTINE
OPTICAL CHARACTERISTICS
OF
VIABLE MICROORGANISMS

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SUMMARY

In the rigors of planetary quarantine procedures it becomes necessary to predict the survivability of viable organisms that become separated from a parent "fly-by" vehicle or lander bus. These organisms will exist as separate entities or as "piggy-back" passengers on spacecraft debris, and they will be exposed to the rigors of space, including solar heating and aerodynamic heating resulting from entry into the planet's atmosphere. In this study, an attempt has been made to define the optical characteristics of a representative test spore (Bacillus subtilis var. niger). A Gier-Dunkle spectral reflectometer was used to determine the reflectance, transmittance, and absorptance of a composite slab containing a deposit of these life cells which are typical of a most hardy species. A technique has been developed to account for the presence of the substrate material in order to obtain the characteristic solar absorptance and total hemispherical emittance of the microorganisms.

The conclusions of the study can be summarized as follows:

a. The test spores will have a characteristic total hemispherical emittance of 0.05 and a characteristic solar absorptance of 0.17. The uncertainty associated with these experimental values is ± 0.04 absolute units.

b. The test spores are, in general, highly transparent, even to the longer infrared waves.

c. Based on limited experimentation in the "far" ultraviolet region of the spectrum (≥ 0.3 microns), the spores seem to be highly sensitive to damaging ultraviolet radiation.

d. It was found that the spores tested had a nominal α_s/ϵ_s ratio of 3.4. However, if the tolerance associated with the experimental measurements is considered, the ratio could be as high as 21 and could result in an average pre-entry temperature of 490°F.

SECTION 1
INTRODUCTION

In the 1970's, a series of unmanned planetary probes and landers will be launched to search for extraterrestrial life. In order for the search to have meaning, the vehicles must not be the transplanter of earth-born life. For such life could confuse the data that life sensors will gather on future landing missions and may even alter or destroy the structure of any native planetary life. Thus, it becomes necessary to assure that the transporter of the sterilized lander vehicle, the nonsterile spacecraft bus, will not introduce direct contamination of the planet.

One step along the road to planetary quarantine is the prediction of the survivability of these "life" cells during their exposure to the extremes of space when they are accidently jettisoned from the nonsterile spacecraft bus. The cells could exist as separate entities in an overall cloud of organisms or as "piggy back" passengers on spacecraft debris. The extremes of space could include not only the obvious solar heating-black space cooling cycles but also the heating environment developed during entry into the Martian atmosphere.

Hence, it becomes necessary to define the thermodynamic properties of these micro-organisms in order to adequately predict their behavior during orbital decay and subsequent entry into Mars. These critical properties include:

Specific heat	A measure of the energy required to advance from one temperature state to another
Solar absorptance	A measure of the radiated energy from the sun, absorbed by the cell
Hemispherical emittance	The ability of a cell to lose thermal energy by radiation to colder surroundings

Note that the thermal conductivity is not considered to be a critical parameter, since a body whose maximum dimension is on the order of 10^{-6} feet can readily be treated as a "thin-skin" isothermal particle.

In this study an attempt has been made to determine experimentally the solar absorptance and total hemispherical emittance of a representative test spore (Bacillus subtilis var. niger) in order that the thermal analyst can predict the temperature environment experienced during their orbital and suborbital excursions and their subsequent entry into the Martian atmosphere.

SECTION 2

EXPERIMENTAL TECHNIQUES

The Gier-Dunkle Absolute Directional Integrating Sphere and Heated Cavity Reflectometers have been used in this program of optical characterization of viable microorganisms. Figure 2-1 illustrates the integrating sphere and associated auxiliary equipment required for operation. Figure 2-2 illustrates the directional heated cavity unit mounted on the source-transfer optical system. Figure 2-3 shows the cross section of both instruments. A schematic of the energy path for both operational modes is shown in Figure 2-4.

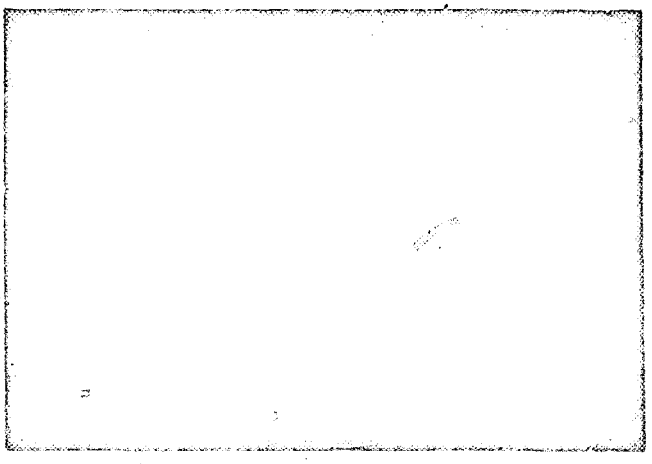


Figure 2-1. Gier-Dunkle Absolute Integrating Sphere Reflectometer and Associated Auxiliary Equipment

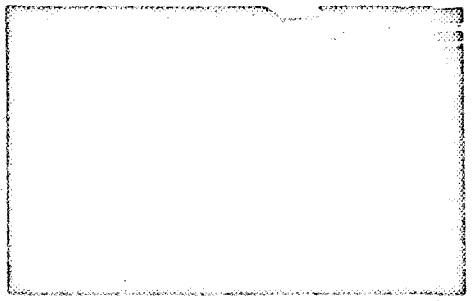
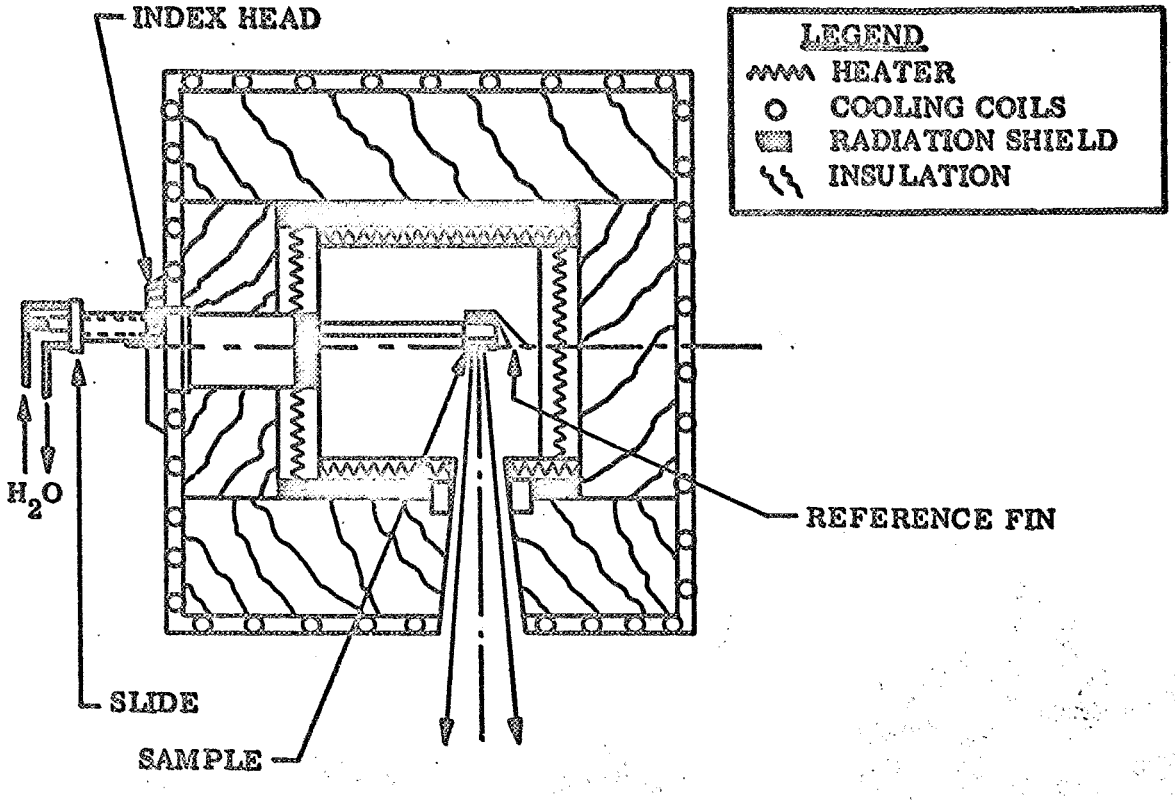
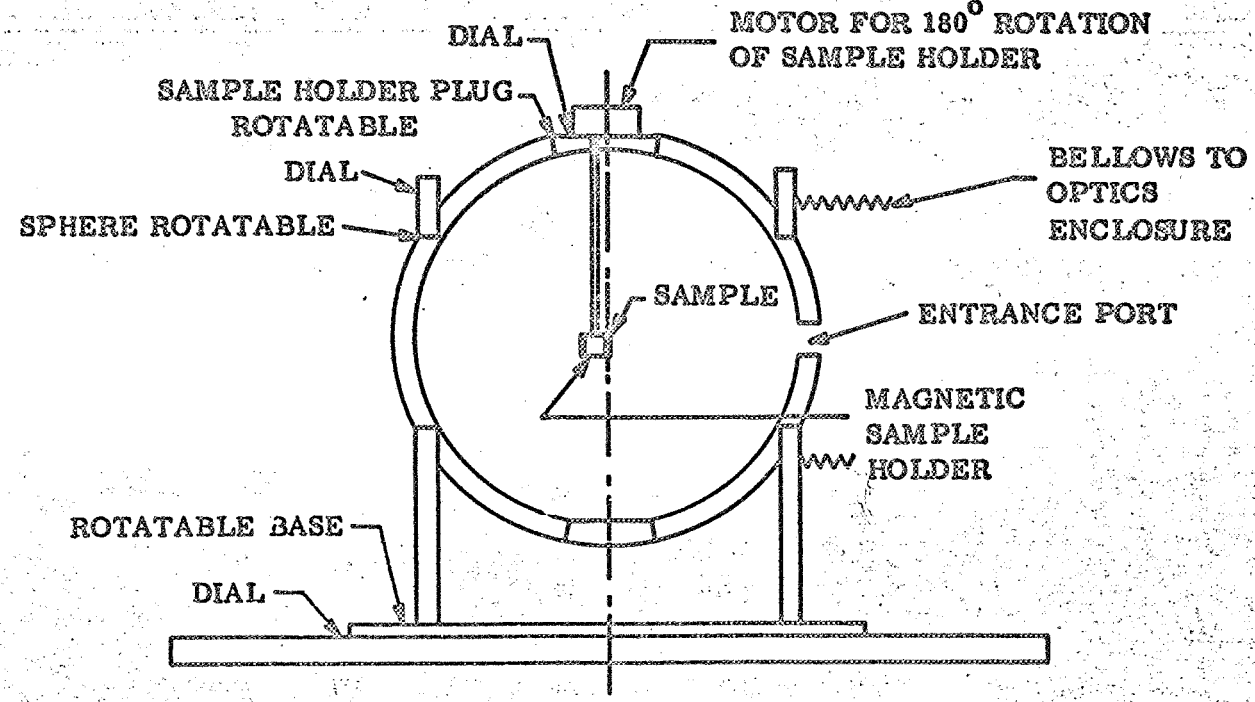


Figure 2-2. Gier-Dunkle Heated Cavity Directional Reflectometer



HEATED CAVITY AND SAMPLE HOLDER



INTEGRATING SPHERE AND SAMPLE HOLDER

Figure 2-3. Cross-Sectional View of Gier-Dunkle Integrating Sphere and Heated Cavity Reflectometer

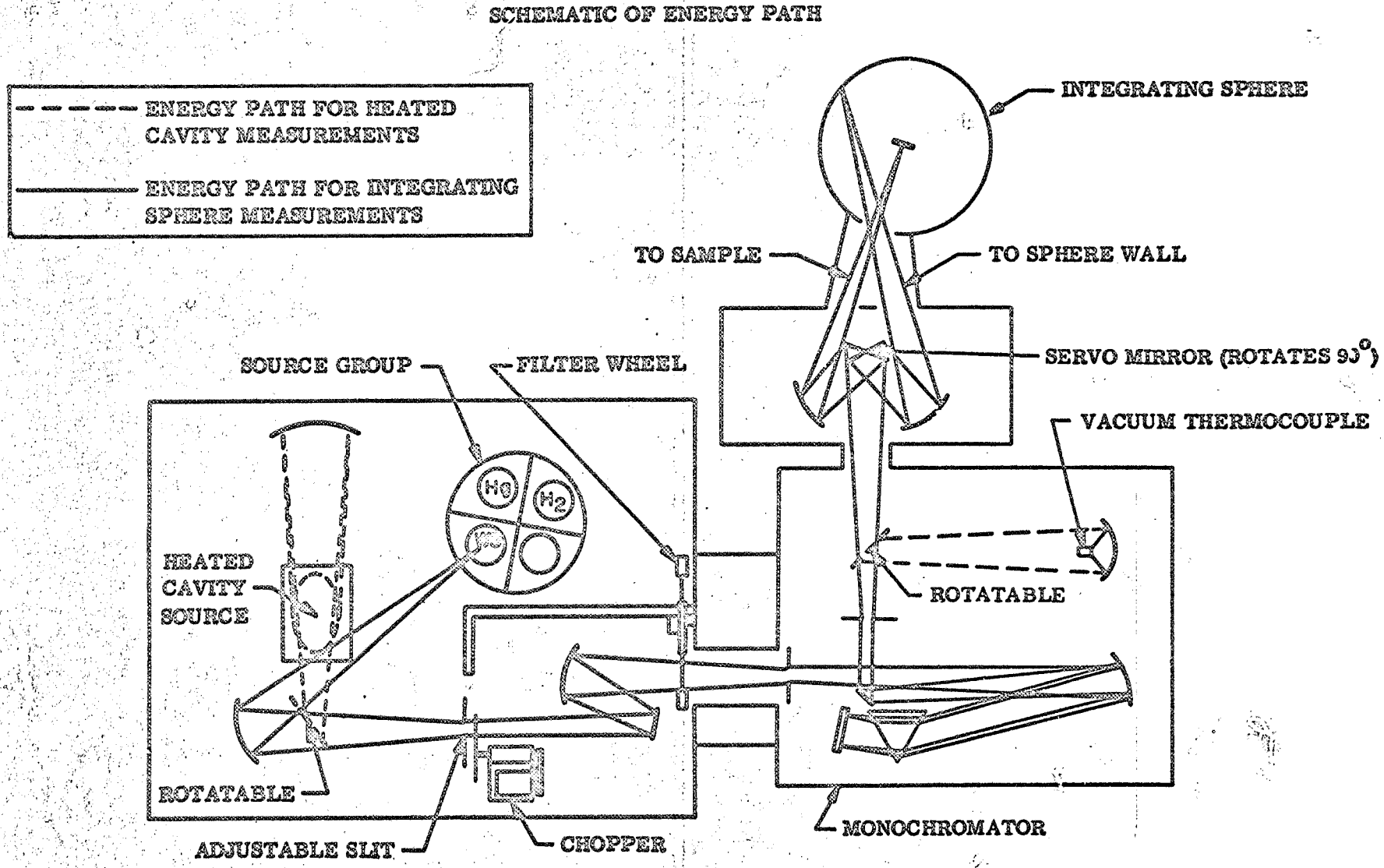


Figure 2-4. Schematic of Energy Path

The Gier-Dunkle integrating sphere is used for measurements of the absolute, directional, spectral reflectance or transmittance in the wavelength region from 0.3 to 3.0 microns. The sphere comprises two 8-inch-diameter cast aluminum hemispheres polished on the interior and smoked with approximately 0.1 inch of magnesium oxide. An auxiliary source and transfer optics unit generates the spectral energy by means of tungsten and hydrogen lamps. This energy is dispersed by a standard Perkin-Elmer Model 98 monochromator equipped with a fused silica prism. The monochromatic radiation is, in turn, directed into the integrating sphere onto a specimen suspended at either the entrance port or at the center of the sphere. The radiation transmitted through or reflected from the specimen and subsequent interflections from the sphere wall (coated with magnesium oxide) cause a diffuse irradiation upon detectors which view the entire sphere but not the specimen. The detector signal is calibrated when the incident energy is directed past the specimen to the sphere wall by means of a remote-controlled rotary mirror in the optical box.

The Gier-Dunkle directional heated cavity is used for measurements of the absolute, directional, spectral reflectance and the binormal transmittance in the wavelength region from 1.0 to 25.0 microns. The assembly consists of a grooved black-nickel cavity with five separate heaters individually controlled to achieve an isothermal black-body cavity operating at 1450°F. The water-cooled sample is positioned in the center of the cylindrical heated cavity, and by rotation of the indexed sample holder, incidence angles between 20° and 75 degrees are achieved. Spectral reflectance data is obtained by comparing the radiant flux reflected from the specimen with that from a platinum fin which is located near the specimen and is used to reduce errors due to nonuniformity of the cavity wall intensity. Binormal spectral transmittance is obtained by inserting the sample into the collimated radiant energy beam between the heated cavity source and the detector. A standard Perkin-Elmer Model 98 monochromator is used to disperse the reflected or transmitted energy and direct it onto a vacuum thermocouple detector. A sodium chloride prism is used for the 1-to-15-micron range, and a potassium bromide prism for the 13-to-25-micron range.

SECTION 3

ANALYTICAL TECHNIQUES

The solar absorptance (α_s) is defined as that fraction of the incident solar flux absorbed by a particular material. It is expressed mathematically as:

$$\alpha_s = \frac{\int_0^\infty \alpha_{s\lambda} S_\lambda d\lambda}{\int_0^\infty S_\lambda d\lambda} \qquad (3\text{-}1)$$

where $\alpha_{s\lambda}$ is the absolute spectral absorptance

S_λ is the monochramatic solar irradiation

Employing the spectral data obtained in the Gier-Dunkle integrating sphere, the solar absorptance can be calculated from Equation 3-1 by the following numerical integration technique:

$$\alpha_s = 0.02 \sum_{i=1}^{50} \left[1-(\rho_i + \tau_i)\right] \qquad (3\text{-}2)$$

where ρ_i and τ_i are the spectral reflectance and transmittance respectively, determined at wavelength intervals corresponding to 2 percent of the solar spectrum of Johnson (Reference 1).

The terms ρ_i and τ_i can be measured as separate entities, or their sum $(\rho_i + \tau_i)$ can be directly determined by suspending the sample in the center of the sphere and detecting the monochromatic energy reflected from the front surface as well as the energy transmitted through the sample.

The total hemispherical emittance is defined as the ratio of the energy emitted in all directions by a particular material to that which would be emitted by a blackbody at the same temperature. It can be expressed mathematically as:

$$\epsilon_H = \int_0^{\infty} \int_0^{2\pi} \int_0^{\pi/2} \left[\epsilon_\lambda(\theta, \phi)\right] \sin\theta \cos\theta \, d\theta \, d\phi \, \frac{I_{b\lambda}}{\sigma T^4} \, d\lambda \qquad (3\text{-}3)$$

where $\epsilon_\lambda(\theta, \phi)$ is the spectral directional emittance

$I_{b\lambda}$ is the monochromatic "blackbody" intensity

T is the absolute temperature of the sample

σ is the Stefan-Boltzman constant

Assuming the spectral emittance to be independent of the azimuthal angle (ϕ), this integration can be approximated by breaking the spectrum into N large intervals each containing Mj sub-intervals and summing as follows:

$$\epsilon_H = \sum_{j=1}^{N} \left\{ \int_0^{\frac{\pi}{2}} \left[\frac{\epsilon(\theta)}{\epsilon(0)}\right]_j d(\sin^2\theta) \sum_{i=1}^{Mj} \left[\epsilon_\lambda(o)_{j,i} \int_{\lambda j, i-1}^{\lambda j, i} \frac{\pi I_{b\lambda}}{\sigma T^4} \, d\lambda\right] \right\} \qquad (3\text{-}4)$$

where $\left[\frac{\epsilon(\theta)}{\epsilon(o)}\right]_j$ is the normalized directional emittance which is insensitive to wavelength in the jth interval.

$\left[\epsilon_\lambda(o)\right]_{j,i}$ is the average normal spectral emittance of the (j,i)th sub-interval.

$\int_{\lambda j, i-1}^{\lambda j, i} \frac{\pi I_{b\lambda}}{\sigma T^4} d\lambda$ is the fraction of the total energy emitted by a "blackbody" at temperature which appears in the (j,i)th sub interval of the spectrum.

SECTION 4

SPECIMEN PREPARATION

Since one is concerned with viable organisms whose maximum dimensions are on the order of 10^{-6} feet, it becomes an impossible task to isolate one, two, or even a dozen of these organisms and attempt to define their optical characteristics. We must, instead, fabricate a specimen that is suitable for experimental studies using the Gier-Dunkle Reflectometers and at the same time is representative of the condition under which the organisms will exist in their journey into Mars.

If the organisms are suspended in a liquid solution which, in turn, is deposited on a suitable substrate, a simple drying process will drive off the liquids and leave behind a dry cloud or smear of microorganisms. The organisms employed were bacterial spores of Bacillus subtilis var. niger, and a discussion of the technique used in preparation can be found in Reference 2. The technique described therein affords a representative sampling of the test spores in smears that are thin enough to be representative of one layer of organisms (photomicrographs will show that the smear is in general composed of 1 or 2 layers of organisms). However, the fact that the spores are now mounted on a substrate that is really nonexistent during the actual flight into Mars is unrealistic. Fortunately the effect of the substrate can be accounted for if its optical characteristics are obtained prior to mounting the spores. This technique will be further discussed in the analysis of the experimental data.

The choice of substrates was limited to materials that would be chemically and biologically compatible with the organisms and the solution containing the organisms. Also, it was necessary to have one substrate material that would be transparent to monochromatic radiation out to 25.0 microns in order to obtain the transmittance of the organisms. Glass was chosen as the substrate for reflectance measurements because of its chemical stability and because its opacity to infrared energy simplified, to some extent, the data reduction. Thin mylar film, approximately 0.00025 inch thick, was used as the substrate in transmittance measurements.

The compatibility of the mylar with the viable organisms was confirmed by M. Koesterer (Reference 2), who prepared the test specimens.

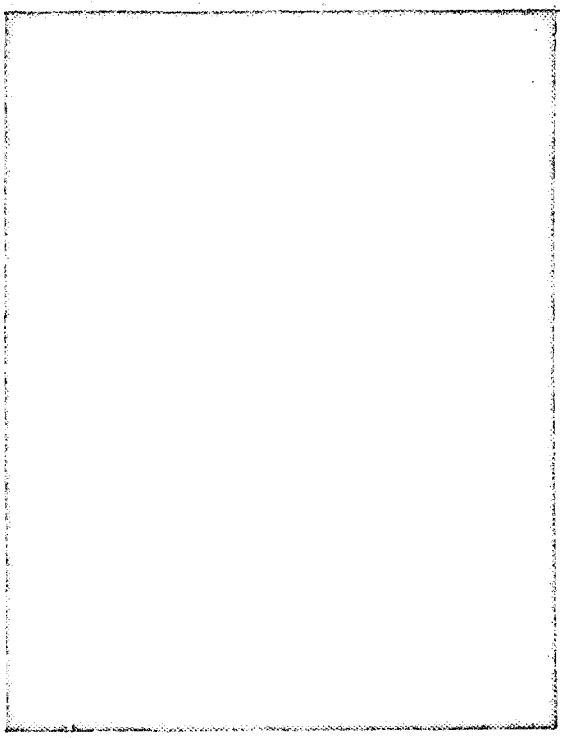
SECTION 5
SPECIMEN DESCRIPTION

As mentioned previously, the microorganisms were prepared on glass and mylar substrates in order to have some physical means of handling during experimentation. An extensive photomicrographic study of the final composite specimens was undertaken in order to ascertain, in general, the condition and in particular the uniformity of the layer of organisms deposited on the particular substrates. Representative photos are included as Figures 5-1 and 5-2.

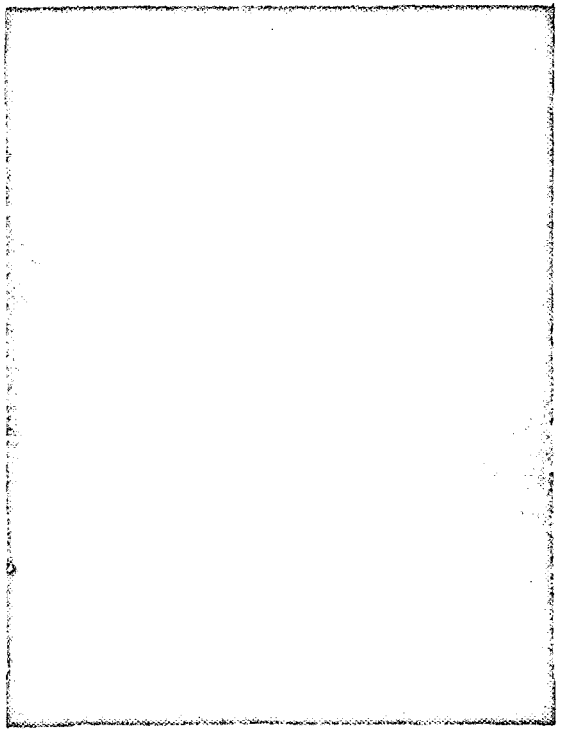
Figure 5-1 presents photos of the microorganisms mounted on a glass substrate. At a magnification of 3x, we see what appears to be a rather irregular, fingerprint-type smear. However, if it is realized that only a very small portion of the sepcimen, approximately 0.02 square inch in the center (see outline in photomicrograph at 3x) is actually used for experimentation, this inital fear of nonuniformity becomes unfounded. At a magnification of approximately 100x, this nonuniformity becomes less exaggerated, and the organisms begin to take on some semblance of individuality.

At 1010x magnification Figure 5-1, it is possible to classify as to size and shape. In general, the cells assume the shape of rounded football-type cylinders with characteristic lengths of 5.8×10^{-6} feet (1.75 microns) and diameters of 3.3×10^{-6} feet. Perhaps the most important detail that can be observed from this photomicrograph is that the smear or cloud deposited on the glass substrate was indeed composed of no more than a few layers of organisms. In fact, careful study shows that only a relatively small percentage of area had as many as two layers and that the major portion was covered with only one layer. Thus, reflectance and transmittance measurements on this specimen will be representative of the values that actually exist for one discrete spore.

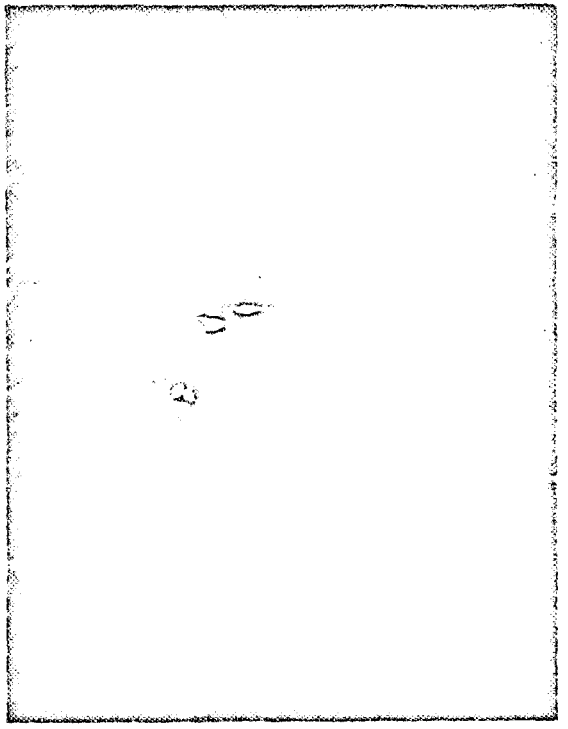
Figure 5-2 presents photomicrographs of the organisms mounted on 0.00025 inch thick mylar film. At a magnification of 505x, the overall uniformity of the smear of organisms is evident. The two photos of different sections of the same test specimen at 1010x magnification again show that the majority of substrate coverage is with one layer of organisms.



MAGNIFICATION = 3X

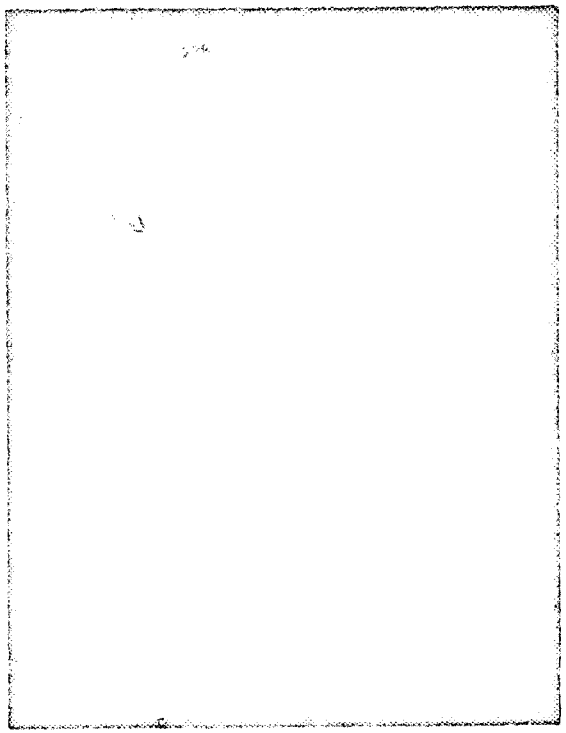


MAGNIFICATION = 100X

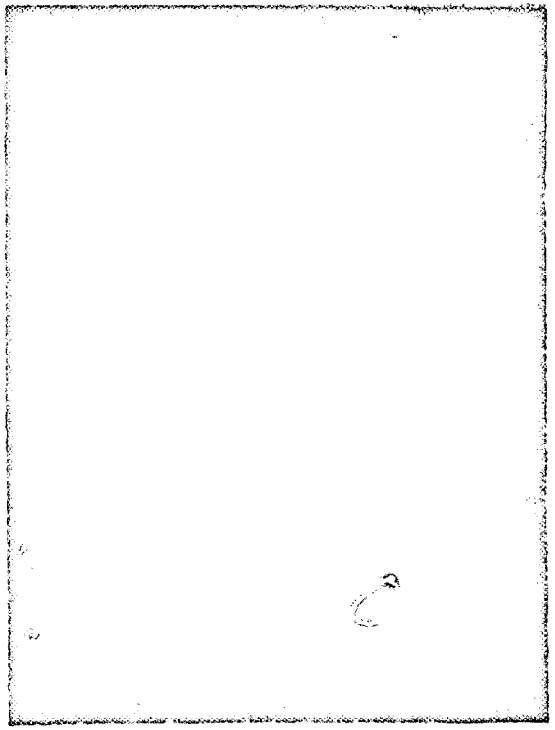


MAGNIFICATION = 1010X

Figure 5-1. Microorganisms on Glass Substrate



MAGNIFICATION = 505X



MAGNIFICATION = 1010X

MAGNIFICATION = 1010X

Figure 5-2. Microorganisms on Mylar Substrate

The difference in intensity and background color of these three photomicrographs is due only to the different filters and exposure times used in the photographic process.

The major premise has been that the substrate is covered with a uniform monolayer of organisms in order that the optical measurements be characteristic on one discrete organism. The question readily arises concerning the bare spots that are visible in the photomicrographs. If it is realized that the area sighted by the Gier-Dunkle Reflectometer, 0.1 inch x 0.2 inch, would manifest itself as a rectangle 50.5 inches x 101 inches in the photomicrograph at 505x magnification (Figure 2-3), it can be seen that the bare spots represent a minimal percentage of the total viewing area. Considering the entire collection of photomicrographs in total, it is judged that between 80 and 90 percent of the sighted area had complete monolayer coverage. This conservative estimate will be manifested in a broader tolerance associated with the experimental results.

SECTION 6

ANALYSIS OF EXPERIMENTAL DATA

6.1 SOLAR ABSORPTANCE

As noted in the discussion of experimental techniques, the Gier-Dunkle Integrating Sphere is used to characterize materials in the solar wavelength region. For a single-layer material, the solar absorptance is generally found by a straightforward scheme of integrating either the spectral reflectance, in the case of opaque materials, or the spectral reflectance plus transmittance in the case of transparent materials and subtracting this integration from unity. However, for a multilayered configuration, such as the organisms-mylar, it becomes necessary to characterize not only the composite but also the second layer substrate material in order to correct for its presence in the composite. Briefly, the procedure is to determine the transmittance of the mylar substrate and then the transmittance of that substrate with a deposit of organisms. The transmittance of the spores alone is then calculated from these two measurements as:

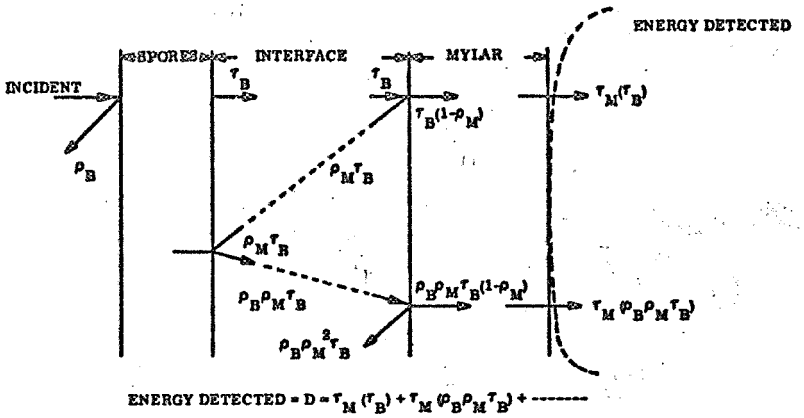
$$\tau_B = \frac{\tau_{APP}}{\tau_m} \qquad (6\text{-}1)$$

where τ_B is the transmittance of the spores

τ_m is the transmittance of the mylar substrate

τ_{APP} is the apparent transmittance of the spores on mylar

Figure 6-1 shows the development of this expression. It is noted that the only assumption in arriving at this relationship is that the mylar substrate has a very low surface reflectance (<0.1) in order that reflections at the spore-mylar interface be negligible. This characteristic of mylar is discussed in Reference 3 and can be further deduced from the high transmittance as determined by our own study.



ENERGY DETECTED = $D = \tau_M(\tau_B) + \tau_M(\rho_B\rho_M\tau_B) + \cdots\cdots$

$\therefore$ SINCE $\rho_M\rho_B$ IS NEGLIGIBLE

$D = \tau_{M\&B} = \tau_M(\tau_B)$

$\tau_B = \frac{\tau_{M\&B}}{\tau_M}$

LEGEND

ρ_M = REFLECTANCE OF MYLAR

ρ_B = REFLECTANCE OF TEST SPORES

τ_M = TRANSMITTANCE OF MYLAR

τ_B = TRANSMITTANCE OF TEST SPORES

D = TOTAL TRANSMITTED ENERGY THROUGH SPORE-MYLAR COMPOSITE

Figure 6-1. Transmittance of Spore-Mylar Composite

The reflectance plus transmittance of the composite of microorganisms and mylar is then determined by allowing the monochromatic light to pass through the sample mounted in the center of the integrating sphere. Again assuming reflectance of the mylar as a negligible component, the energy detected is:

$$E = \rho_B + \tau_M(\tau_B) \qquad (6\text{-}2)$$

where E is the energy detected

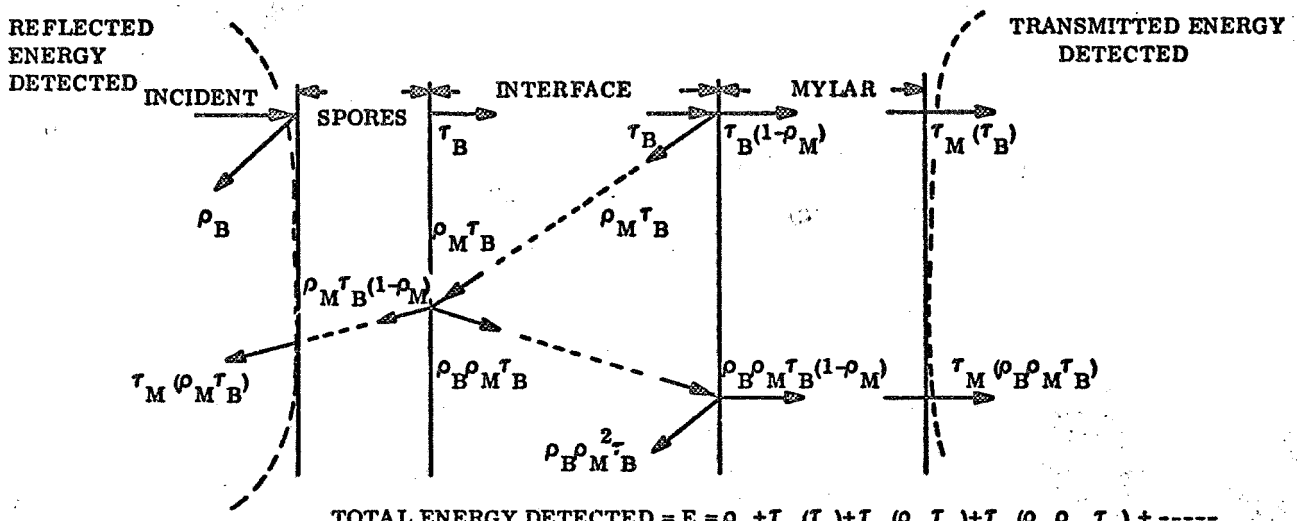
ρ_B is the reflectance of the spores

τ_M is the transmission of the mylar

τ_B is the transmission of the spores

Figure 6-2 shows this development. Having the transmission of the spores as defined by Equation 6-1, it then is a simple matter to calculate the reflectance (ρ_B) from Equation 6. The absorptance of the spores (α_B) is then determined from Kirchoff's law as:

$$\alpha_B = 1 - \tau_B - \rho_B \qquad (6\text{-}3)$$



TOTAL ENERGY DETECTED = $E = \rho_B + \tau_M(\tau_B) + \tau_M(\rho_M\tau_B) + \tau_M(\rho_B\rho_M\tau_B) + \text{-----}$

$\therefore$ SINCE ρ_M IS SMALL

$E = \rho_B + \tau_M(\tau_B)$

LEGEND:

ρ_M = REFLECTANCE OF MYLAR

ρ_B = REFLECTANCE OF TEST SPORES

τ_M = TRANSMITTANCE OF MYLAR

τ_B = TRANSMITTANCE OF TEST SPORES

E = TOTAL TRANSMITTER PLUS REFLECTED ENERGY THROUGH SPORE-MYLAR COMPOSITE SPORE

Figure 6-2. Transmittance Plus Reflectance of Spore Mylar Composite

6.2 TOTAL EMITTANCE

The Gier-Dunkle heated cavity was used to measure the spectral properties of the organisms in the infrared region of the wavelength spectrum. It is this region (>5.0 microns) that represents 98 percent of the radiation of a blackbody at 100°F.

Again, it was necessary to account for the presence of an extraneous substrate, and a technique similar to the solar absorptance measurements was employed. The spectral transmittance of the mylar substrate, with and without a deposit of microorganisms, was obtained by insertion into the collimated beam of radiant energy between the heated cavity source and the vacuum thermocouple detector. The transmittance of the organisms alone was then calculated from Equation 6-1 as:

$$\tau_B = \frac{\tau_{APP}}{\tau_m} \quad \text{(See Figure 6-1).} \qquad (6\text{-}4)$$

Again, it is assumed that reflections at the spore-mylar interface represents a negligible portion of the transmitted component.

The reflectance of the organisms was determined from an apparent reflectance of a spore-glass composite. In brief, the transmittance of the organisms is coupled with the measured reflectance of the "virgin" glass substrate and the reflectance of the organisms alone is calculated by:

$$\rho_B = \rho_{APP} - \rho_G \tau_B^2 \qquad (6\text{-}5)$$

where ρ_B is the reflectance of the spores

ρ_G is the reflectance of the glass substrate

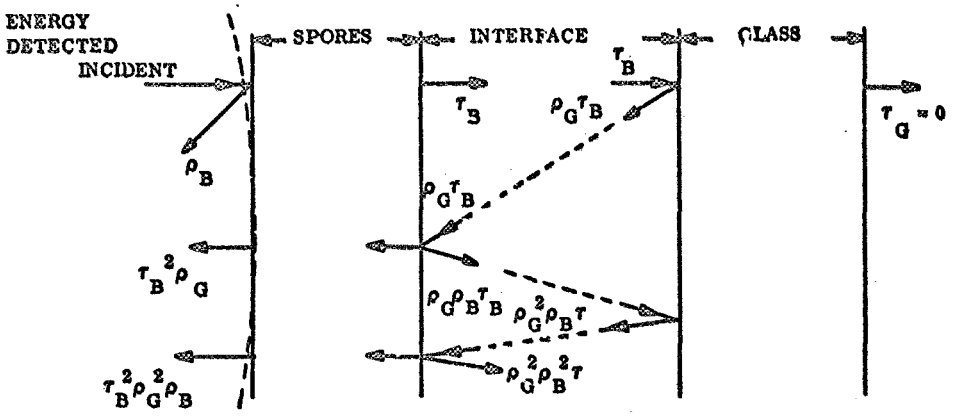
τ_B is the transmittance of the spores

ρ_{APP} is the apparent reflectance of the spores-glass composite.

Figure 6-3 shows the development of this expression.

From Kirchhoff's law the emittance is calculated as:

$$\epsilon_B = 1 - \rho_B - \tau_B \qquad (6\text{-}6)$$



ENERGY DETECTED $= \rho_{APP} = \rho_B\tau_B^2 + \rho_G^2\rho_B\tau_B^2 + \cdots$

$\therefore$ SINCE $\rho_G^2\rho_B$ IS NEGLIGIBLE

$$\rho_{APP} = \rho_B + \rho_G\tau_B^2$$

AND: $\rho_B = \rho_{APP} - \rho_G\tau_B^2$

WHERE:

ρ_G = REFLECTANCE OF THE GLASS SUBSTRATE

ρ_B = REFLECTANCE OF THE TEST SPORES

τ_B = TRANSMITTANCE OF THE TEST SPORES

τ_G = TRANSMITTANCE OF THE GLASS = 0 (FOR WAVELENGTHS > 5.0 MICRONS)

ρ_{APP} = APPARENT REFLECTANCE

Figure 6-3. Apparent Reflectance of Spore-Glass Composite

SECTION 7

RESULTS

Figure 7-1 presents the absorptance of the microorganisms as a function of wavelength. Each data point, as calculated from Equation 6-3, represents the absorptance in a wavelength interval corresponding to 2 percent of the extraterrestrial solar spectrum.

Note that at the lower end of the spectrum the absorptance increases sharply, indicating that the organisms may be sensitive to ultraviolet radiation. This high UV absorptance is characteristic of most viable organisms even in the simplest form and should be considered as one of the "kill" mechanisms together with temperature-time history kills.

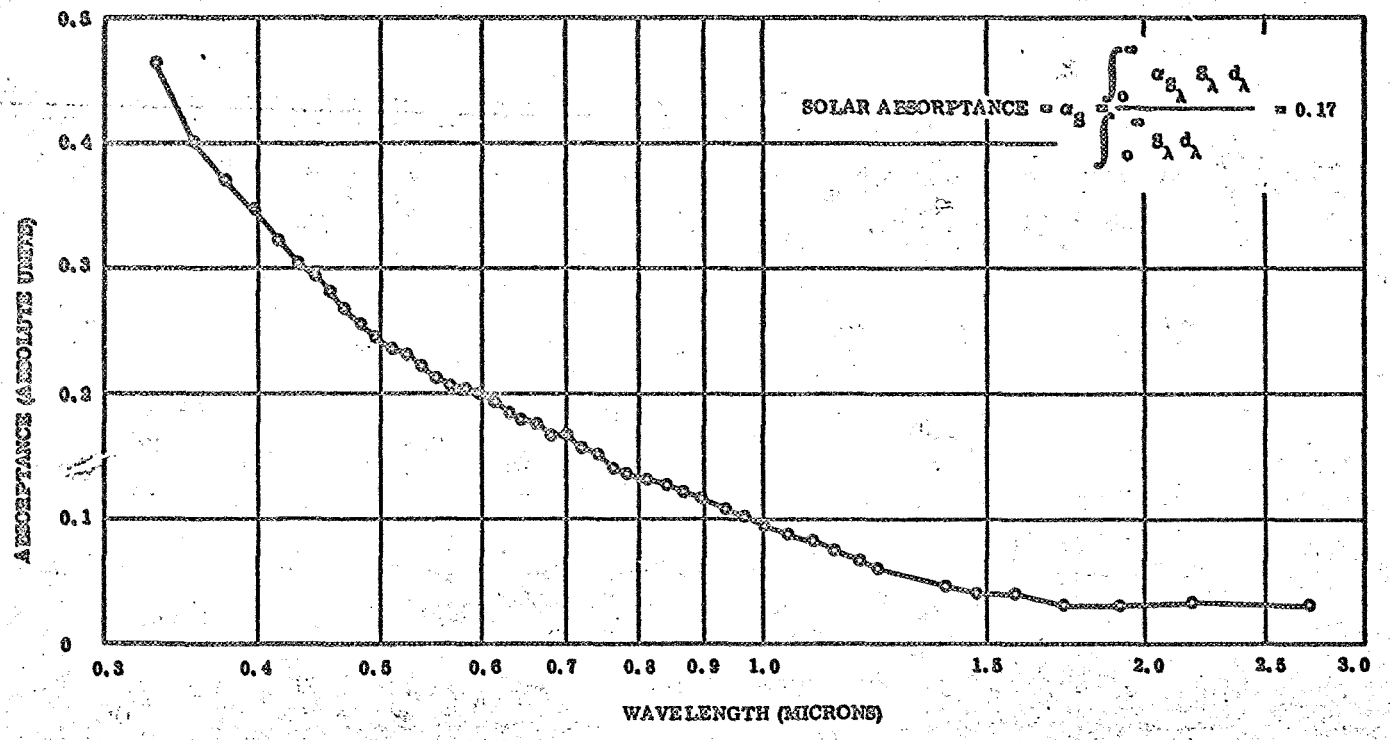


Figure 7-1. Spectral Absorbtance of Bacillus subtilis var. niger Spores
Solar Region Spectrum

Integration of the spectral data of Figure 7-1 results in a solar absorptance of 0.17 as characteristic of the particular breed of organisms (spores of Bacillus subtilis var. niger)

considered in this study. It is important to note that this relatively low solar absorptance is a direct result of the transparency of the cells since their reflectance, calculated from Equation 6-2, was negligible.

Figure 7-2 presents the normal spectral emittance of the microorganisms as calculated from Equation 6-6. The extremely low spectral emittance, which is approximately zero in some cases, is the result of the high transparency of the organisms since the reflectance calculated by Equation 6-5 was negligible. Integration of this normal spectral data, with respect to a black body at 100°F, gives a total normal emittance of 0.04 as characteristic of these Bacillus subtilis spores at 100°F. The parameter required in radiation heat transfer analysis is the total hemispherical emittance and, based on the theory of Jakob (Reference 4), the ratio of total normal to total hemispherical emittance for a material with a total normal emittance of 0.04 is 1.28. Hence the total hemispherical emittance using this approach is calculated to be 0.05.

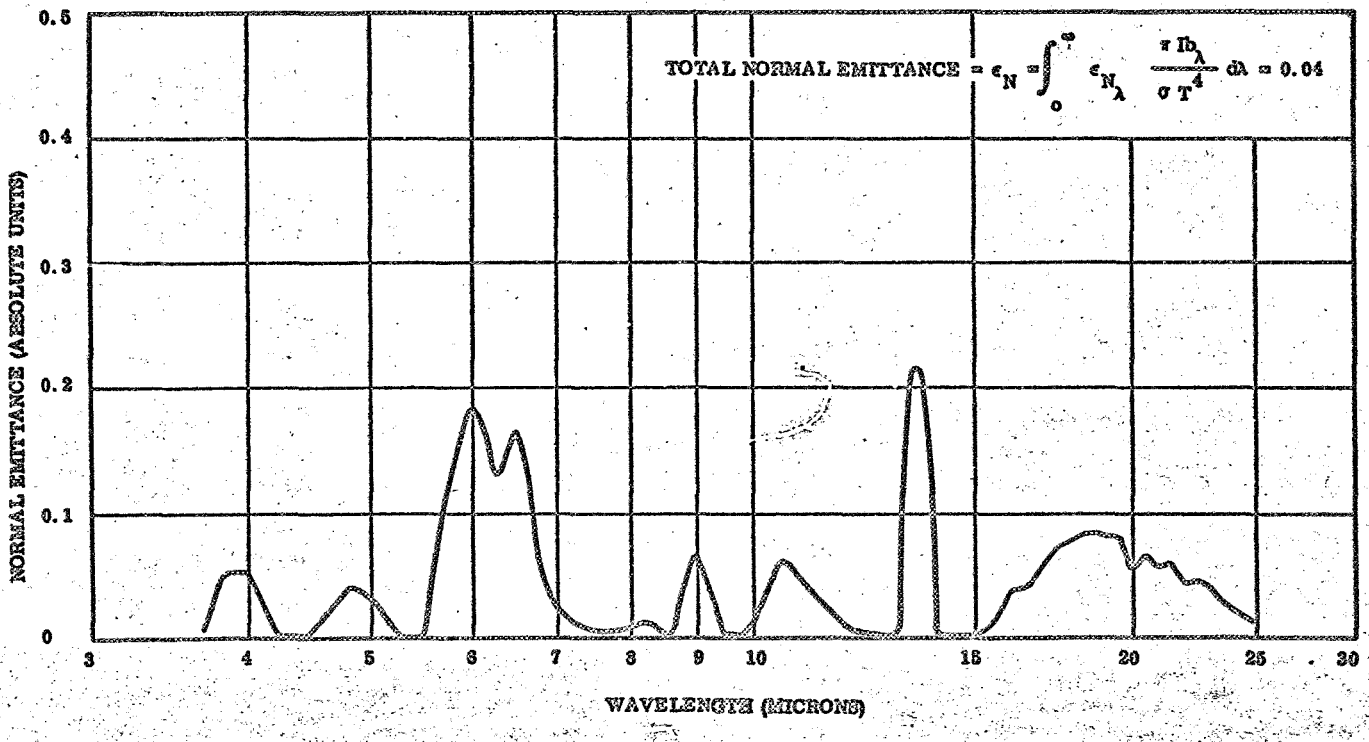


Figure 7-2. Spectral Normal Emittance of Bacillus subtilis var. niger

The uncertainty associated with these values of solar absorptance and hemispherical emittance is ± 0.04 absolute units, which include a measurement tolerance of ± 0.015 inherent in the Gier-Dunkle reflectometers and an uncertainty of ± 0.025 due to uniformity of sample preparation, diffuseness of mylar film, and approximations in data reduction schemes.

It is significant to note that although the organisms will absorb a small percentage of incident solar flux, their average temperature during an orbital environment in the vicinity of Mars will be relatively high. In the absence of aerodynamic heating, the heat balance of a cylindrical cell oriented normal to the solar flux is expressed only in terms of solar heating and radiation cooling. This equilibrium state can be expressed mathematically as:

$$\text{Heat IN} = \text{Heat OUT} \tag{7-1}$$

neglecting planetary emission and assuming a Lambertian absorptance of the solar flux:

$$\text{Heat IN} = (\alpha_B) \int_{-\frac{\pi}{2}}^{\frac{\pi}{2}} (\vec{S} + \vec{R})(\cos\theta)\,(h)\,(r)\,d\theta \tag{7-2}$$

therefore

$$\text{Heat IN} = (\alpha_B)\ (2\,rh)\ (\vec{S} + \vec{R}) \tag{7-3}$$

and neglecting end effects;

$$\text{Heat OUT} = (2\pi\,rh)\ (\epsilon_B)\,\sigma\,T^4 \tag{7-4}$$

where $\vec{S}$ is the solar constant for the planet Mars equal to 0.053 Btu/ft^2 - sec (Reference 4)

$\vec{R}$ is the Planetary Albedo near Mars equal to 0.16 times S (Reference 5)

h is the length of the cylindrical cell

r is the radius of the cell

α_B is the solar absorptance of the test spores

ϵ_B is the total hemispherical emittance of the test spores

T is the absolute temperature in $^\circ$R

σ is the Stefan-Boltzmann constant

Solving Equation 7-1 for temperature gives:

$$T = \sqrt[4]{\frac{\alpha_B}{\epsilon_B} \cdot \left(\frac{\vec{S} + \vec{R}}{\pi}\right) \cdot \frac{1}{\sigma}} \qquad (7\text{-}5)$$

Thus, the equilibrium temperature of the organisms is a direct function of the ratio of solar absorptance to hemispherical emittance (α_B/ϵ_B). Solving Equation 7-5 with the value of α_B/ϵ_B obtained in this study gives an average equilibrium temperature of 620°R (160°F). However, if we consider the tolerance associated with the experimental results, we see that a α_B/ϵ_B ratio as high as 21 is possible resulting, in an equilibrium temperature as high as 950°R (490°F). Thus, orbital and suborbital solar heating should not be completely rejected as a possible "kill" mechanism but should be considered together with the kills caused by entry into the Martian atmosphere.

SECTION 8

CONCLUSIONS

The microorganisms studied have proven to be highly transparent to both visible and infrared radiation and hence possess a low total hemispherical emittance of 0.05 and a solar absorptance of 0.17. Another interesting result is the relatively high ultraviolet absorptance of the organisms. However, this should not be surprising, since most life forms, as we know them on a macroscopic level, have a high ultraviolet sensitivity.

The conclusions of this study are as follows:

a. The test spores have a characteristic total hemispherical emittance of 0.05 and a characteristic solar absorptance of 0.17. The uncertainty associated with these experimental values is ± 0.04 absolute unit.

b. The spores are, in general, highly transparent, even to the longer infrared waves.

c. Based on limited experimentation in the "far" ultraviolet region of the spectrum (> 0.3 microns), the spores seem to be highly sensitive to damaging ultraviolet radiation.

d. It was found that the Bacillus subtilis test spores had a nominal α_B/ϵ_B ratio of 3.4. However, if the tolerance associated with the experimental measurements is considered, the ratio could be as high as 21 and could result in an average pre-entry temperature of 490°F.

SECTION 9

RECOMMENDATIONS

It has been found that these unicellular microorganisms have a certain degree of sensitivity to ultraviolet radiation. It is therefore recommended that a program be initiated to investigate the effect of this damaging radiation on the life cycle of these viable cells. It is felt that ultraviolet absorption could be a major "kill" mechanism, perhaps overshadowing even the aerodynamic heating "kill" affected during entry into the Martian atmosphere.

At the onset of this report, it was noted that together with the solar absorptance and hemispherical emittance, there looms, as a critical thermodynamic property, the specific heat of the organisms. This property, which can be thought of as an effective resistance to temperature change, is basic in defining the aerodynamic heating behavior of an entering cell. It is recommended that a program be initiated to experimentally determine this specific heat parameter in order to refine analytical predictions of the temperature-time history of organisms entering the Martian atmosphere. The small specimen size and overall accuracy (±5 percent) of the Perkin-Elmer Differential Scanning Calorimeter make it well suited for a study of this type. It would be a relatively simple measurement in comparison with spectral reflectance determinations to obtain the specific heat of a sample of microorganisms with a mass on the order of 10 milligrams.

SECTION 10

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